With permission, reprinted from ICARUS, vol. 15, no. 3, December 1971, pp. 363–367.

N75 13741

Geological Provinces of the Near Side of the Moon[1]

J. F. McCAULEY AND D. E. WILHELMS

U.S. Geological Survey, Center of Astrogeology, Flagstaff, Arizona 86001

Received July 23, 1971; revised August 2, 1971

Systematic geologic mapping of the near side of the Moon has provided the basis for defining and delineating the major geological provinces of the near side. From the nature of the provinces and their distribution patterns a general historical sequence evolves. Five main surface-shaping periods are recognized: (1) one of intense early impact cratering; (2) another, probably overlapping the first, during which the impact basins were formed; (3) a prolonged period of varied terra volcanism; (4) a short period of mare volcanism that resulted in filling of the multiring basins; and (5) a period of diminishing volcanic activity continuing up to the time of formation of the last ray craters.

The relative sequence in which most of the Moon's major surface features formed has been determined from systematic lunar geologic mapping begun by the U.S. Geological Survey in 1961 (Shoemaker and Hackman, 1962; McCauley, 1967; Wilhelms, 1970). The data used were almost exclusively photographic, starting with the best available telescopic photographs and later supplemented by the Ranger, Surveyor, and Lunar Orbiter photographs. The most productive of these flights from the standpoint of an improved regional understanding of the Moon was Orbiter IV which provided nearly uniform 80-m resolution coverage of most of the near side. Preparation of a geologic map of the near side at 1:5,000,000 scale commenced with the final acquisition of the Orbiter IV data late in 1967. This map (Wilhelms and McCauley, 1971) is a synthesis built upon the results from the 44 quadrangles of the U.S. Geological Survey's 1:1,000,000 scale systematic program and it summarizes our current understanding of the regional geology of the near side. It was completed in manuscript form prior to Apollo 11; preliminary Apollo 11 and 12 results were, however, incorporated during manuscript processing. These data are consistent with the previously determined relative stratigraphy and the lithologic interpretations presented in the text that accompanies the map.

Various derivative products that depict certain aspects of the Moon's crustal evolution have been prepared from the near side map. One of these to be published at the 1:10,000,000 scale shows the major geologic provinces as now recognized (McCauley and Wilhelms, in preparation). It is reproduced in generalized form and at reduced scale in Fig. 1 which represents an interim product pending review and publication of the 1:10,000,000 scale map.

As in the case of terrestrial geologic province maps, each unit consists of a related rock assemblage and is characterized by a similar inferred origin or a distinctive history. The provinces differ markedly in relative age and regional distribution pattern; it is these differences that lead to a general understanding of the sequential evolution of the near side.

A descriptive name and a generalized order of formation, from the youngest to the oldest, is given in the caption of Fig. 1. The younger provincial units lie mostly in depressions and are interpreted as volcanic in origin. These include the dark mantles (dm) which cover terra units of lighter albedo and frequently lie across mare-terra contacts. They are interpreted as thin veneers of pyroclastic materials that formed contemporaneously with some

[1] Publication authorized by the Director, U.S. Geological Survey.

© 1972 by Academic Press, Inc.

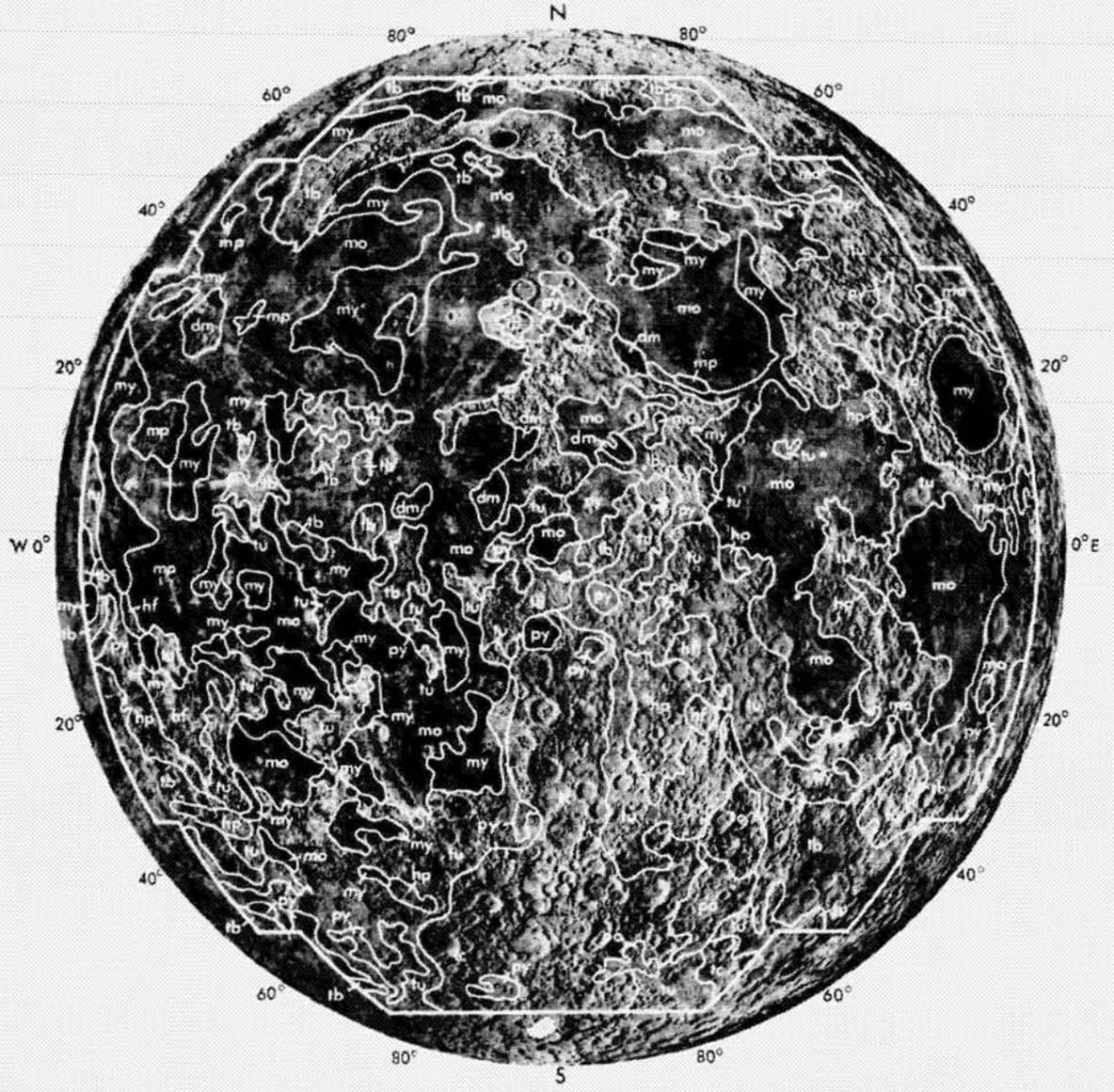

FIG. 1. Geologic provinces of the near side of the Moon. Approximate scale 1:25,000,000. Base is Mosaic LEM-1, 3rd edition, 1966, prepared by the U.S. Air Force Aeronautical and Chart Information Center. Explanation of geologic symbols: dm—dark mantles; mp—mare plateaus; my—mare, young; mo—mare, old; py—plains, young; hf—hilly and furrowed; hp—hilly and pitted; tb—terra of younger basins; po—plains, old; tu—terra, undivided; tc—terra, cratered. Solid line indicates province boundary, dashed where obscured by younger (unmapped) deposits.

of the mare basalts but which are mostly later than the main pulse of mare flooding. Their very dark albedo suggests a distinctive composition and possibly a more deep seated origin than for the maria. The plateau units (mp) within the maria, of which the Marius Hills region is the largest and best example, consist predominantly of aggregates of cones and domes that lie on broadly elevated plateaus or shield-like structures. These plateaus are later than the adjacent maria and are interpreted to consist of pyroclastics and relatively viscous flows of the same or more probably slightly different composition than the maria (McCauley, 1969). They may represent the late stage fractionation products of mare flooding, and thereby be more felsic in composition. The younger mare (my) is generally darker, less cratered, and more patchy in its distribution than most of the older mare exposed on the near side. Contacts tend to be gradational or are diffuse because of superposed ray cover. Some boundaries, however, are coincident with faint color differences (McCord, 1969). This unit is interpreted to consist of relatively thin flows with possible subordinate pyroclastic deposits present. The unit mapped probably resembles petrologically the rocks sampled by Apollo 12. The older mare (mo) is of dark to intermediate albedo and lies almost exclusively within the major near side multiring basins or in concentrically positioned structural troughs that are part of their associated "ring" systems. The surface of this unit marks the end of the main pulse of mare flooding and it defines the top of the Imbrian System (Wilhelms, 1970). Representative samples of this unit were collected during the Apollo 11 mission. The young plains (py) of light albedo partly fill some of the basins, irregular terra depressions, and the floors of large ancient terra craters. Where in contact with the mare they are embayed and, therefore, older than the mare; they also show a demonstrably higher frequency of small craters. This unit, although subordinate in areal extent to the mare materials on the near side, is of considerable significance as a Moon-wide depression filler; on the far side it occupies the floors of most of the multiring basins and large craters. Its origin remains unclear. It could consist mostly of impact-lightened older mare or compositionally distinct volcanic flows that preceded the main pulse of near-side magmatic activity.

Two distinct types of terra that appear to modify older more densely cratered surfaces are now recognized and their distribution pattern shown on the map (units hf and hp). The first, which is described mostly as hilly and furrowed, consists of closely spaced linear structures with interspersed equidimensional hills. The linear structures show furrows along their crests and closely resemble terrestrial fissure cones. The second unit consists of rolling plains and plateaus which show numerous closely spaced rimless or smooth rimmed pits, mostly in the 2–6km size range. Within these provinces few large pre-Imbrian craters are present; those that do occur appear to be embayed or partly covered by these units. Both are interpreted as volcanic in origin and as the products of a pre-mare episode of terra volcanism that is probably compositionally distinct from the later basalt flooding of the near side basins (Wilhelms and McCauley, 1969). One patch of hilly and furrowed material in the Descartes region is the current target for Apollo 16.

The terra of the younger basins (tb) consists of the recognizable ejecta blankets, the elevated and most prominent parts of the encompassing structural rings, and the radially lineated terrain surrounding the three youngest near-side basins—Orientale, Imbrium, and Nectaris. Also included is the most prominent ring around the Crisium basin although it does not show a now recognizable ejecta blanket. This unit is interpreted as a lithologically complex mixture of shocked and unshocked breccias excavated from deep within the central parts of the basin and redistributed as much as a 1000km or more over the Moon's surface. Rocks of this type were sampled in the Fra Mauro region during the Apollo 14 mission. They clearly should consist of relatively primitive lunar materials—some

of which may be magmatic—and the reworked ejecta of the older basin blankets and impact craters that were located within the region of the crater produced during multiring basin formation. Heavily cratered plains (po) fill several large depressions in the southeast quadrant of the near side. Most of the superposed craters appear to be of Imbrian age and many are probable secondary impact craters of the Imbrium basin. These plains generally resemble those of unit py but were emplaced before the Imbrium event whereas unit py truncates many Imbrium related structures. These older plains are, however, younger than the Nectaris event which is of pre-Imbrian age. Their general similarity to the younger plains suggests a common origin.

The most extensive near-side terra province (tu) consists of nondescript blocky hills and unevenly filled irregular to sometimes linear depressions along with what appear to be segments of mantled craters. Probable volcanic landforms are sparsely distributed and the unit most likely consists largely of erosionally degraded, interlayered ejecta from the more ancient near-side basins such as Crisium, Humorum, and Serenitatis. Cratered terra (tc) occupies most of the south-central part of the near side. This unit was named the macro-crater province by Hackman and Mason (1961). It consists mostly of closely spaced 50–150km craters of early pre-Imbrian age; probable volcanic materials, except for the terra plains in crater floors, are absent as are recognizable basin related deposits. The almost shoulder to shoulder array of ancient craters which characterizes this province suggests that it represents a very primitive surface little modified by later internal activity or basin-forming events. It lies outside the range of deposition and structural dislocation associated with multiring basin formation, which probably accounts for its preservation.

The definition and delineation of these major near-side provinces yields the following general historical sequence: (1) An early period of intense bombardment that produced a surface essentially saturated with craters in the 50–150km size range. (2) A period of impact basin formation, probably overlapping the first period, during which ejecta blankets were emplaced around all of the multiring basins; older basin structures and blankets were catastrophically aged by the newer. (3) A period of terra volcanism which began during basin formation and continued at least until after the Imbrium event. Some of the younger plains, appear to postdate Orientale. (4) A main pulse of basaltic volcanism, also of relatively short duration, which flooded the depressed parts of the near-side basins to varying levels. (5) Diminished volcanic activity, possibly of distinct composition, continuing up through the time of formation of the last ray craters. Contemporaneously with these last four major evolutionary episodes, impact cratering continued but probably at a progressively diminishing rate, for simplicity these craters have not been included; where present and of large size (on the order of 100km) the major provincial boundaries have been extrapolated beneath these younger features.

References

Hackman, R. J., and Mason, A. C. (1961). Engineer special study of the surface of the Moon. *U.S. Geol. Survey Misc. Geol. Inv.* Map I-351.

McCord, T. B. (1969). Color differences on the lunar surface. *J. Geophys. Res.* **74**, 3131–3142.

McCauley, J. F. (1967). The nature of the lunar surface as determined by systematic geologic mapping. *In* "Mantles of the Earth and Terrestrial Planets" (S. K. Runcorn, Ed.), pp. 431–460. Interscience, New York.

McCauley, J. F. (1969). The cones and domes of the Marius Hills region. *Trans. Amer. Geophys. Union* **50**, 229.

McCauley, J. F., and Wilhelms, D. E. (in preparation). The geologic provinces of the near side of the Moon.

Shoemaker, E. M., and Hackman, R. J. (1962). Stratigraphic basin for a lunar time scale. *In* "The Moon—Symposium 14 of the International Astronomical Union" (Z. Kopal and Z. K. Mikhailov, Eds.), pp. 289–300. Academic Press, New York.

WILHELMS, D. E. (1970). Summary of lunar stratigraphy—Telescopic observations. *U.S. Geol. Survey Prof. Paper* 599-F, 47.

WILHELMS, D. E., AND MCCAULEY, J. F. (1967). Volcanic materials in the lunar terrae—Orbiter observations. *Trans. Amer. Geophys. Union* 50, 230.

WILHELMS, D. E., AND MCCAULEY, J. F. (1971). Geologic map of the near side of the Moon. *U.S. Geol. Survey Misc. Geol. Inv.* Map I-703.